iBROW project newsletter #4

December 2016

Welcome to the fourth iBROW project newsletter!

iBROW is a research project supported by the European Commission through Horizon 2020 under Grant Agreement 645369.

iBROW is a collaborative research project addressing the growing requirement for high bit rate short range wireless comms using resonant tunnelling diodes (RTDs). The project is supported by the European Commission through Horizon 2020. This newsletter contains:

- *iBROW presence at European Microwave Week (London; Oct-2016)*
- *An update on III-V on Si wafer bonding for RTD processing from CEA-LETI*
- *The first reported RTDs on direct growth silicon wafers from IQE*
- *A report on integrated antenna design and simulation from INESC TEC*
- *Details of iBROW input to standards for wireless comms led by TU Braunschweig*

The project is currently defining its demonstration, which could include elements requested by newsletter readers. If you have any technology which may be relevant please get in touch (email below)! More info is available on the website (www.ibrow-project.eu).

iBROW booth at European Microwave Week 2016

Thanks to all the visitors to the iBROW booth and workshop at EuMW 2016. Also many thanks to Cascade Microtech and Keysight for lending the test station and analyser. There was a great deal of interest, and the discussions have kicked off several new activities.

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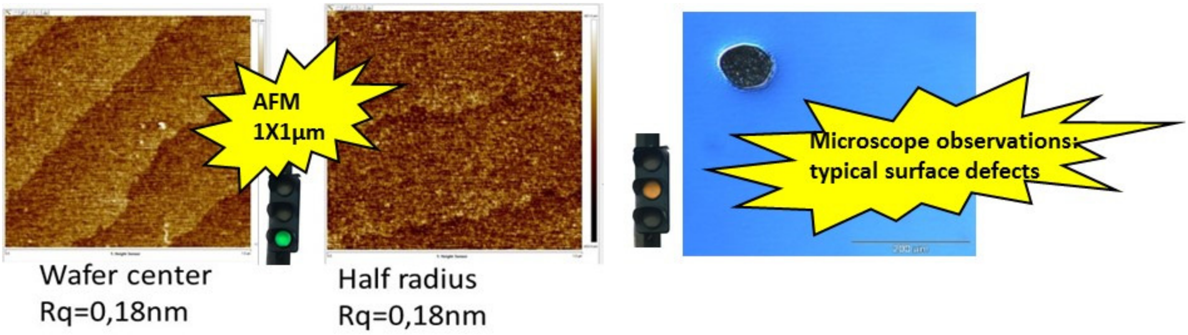
Direct wafer bonding: III-V on silicon

Direct wafer bonding refers to a process by which two mirror-polished wafers are put into contact and held together at room temperature by adhesive forces, without any additional materials. This technique has become the technology of choice for materials integration in various areas of microelectronics, micro-electro-mechanical systems and optoelectronics. In the effort to introduce III-V materials into low cost silicon platform manufacturing, the wafer bonding approach could be of great interest due to the well-known limitations of growing compound III-V hetero-epitaxial layers directly onto silicon (see page 3).

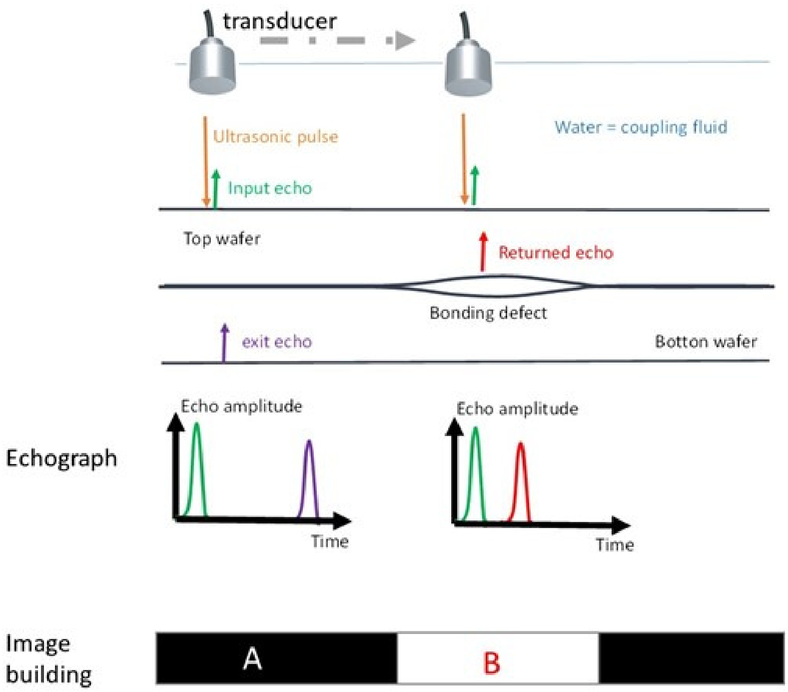
Wafer bonding is usually performed in a clean room with hydrophilic or hydrophobic surfaces, obtained via physical and chemical surface preparation. Smooth surfaces and suitable surface chemistry are needed to enable direct wafer bonding. Furthermore, very clean surfaces, low particle and metallic contamination levels are necessary to reach high yield and defect-free bonded structures. The figure below illustrates the first material surface characterisation of RTD structure on InP wafer.

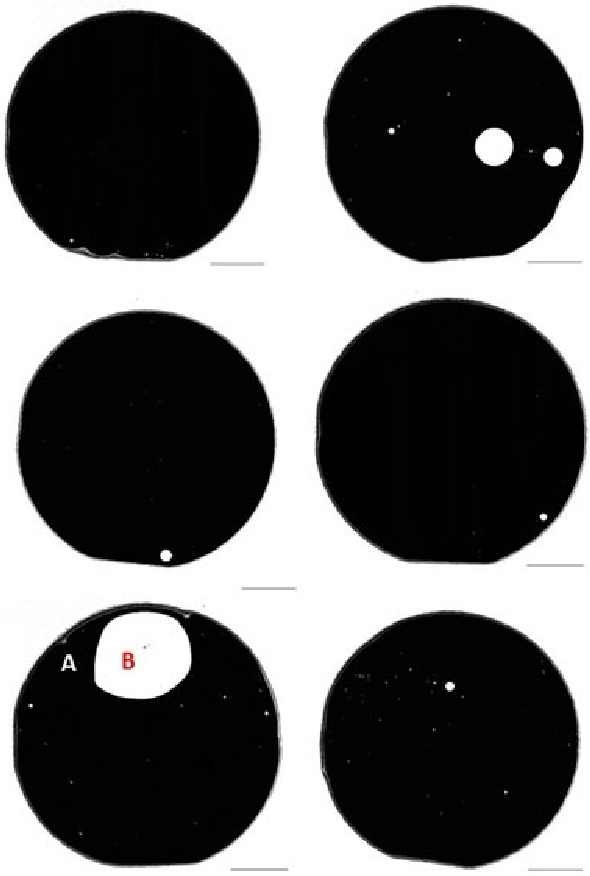
Surface characterisation of InP wafer with RTD structure.



After a specific surface cleaning, wafers are bonded and then annealed to improve the bonding quality. The bonding interface is characterised by scanning acoustic microscopy. The figure below shows direct bonding results of the first batch of InP wafer with RTD structure.

Scanning Acoustic Microscopy (SAM): Acoustic characterisation of the bonding interface for the first batch InP wafer (right) and the principles of SAM operation (below).





The micro-roughness is compatible with direct bonding but some surface defects could generate large bonding defects. Surface defects of the epitaxial layer are still the main issue for direct bonding. The InP wafers with epitaxial layers provided by III-V Lab exhibited surface defect densities low enough to reach a good bonding yield. Large bonded areas, shown in black in the previous figure, will allow the manufacture of RTD devices by III-V Lab. An alternative direct bonding process using a planarised SiO_2 deposited layer is also of interest in order to limit the impact of the initial surface defects on the bonding yield and will be tried for the next step of the project.

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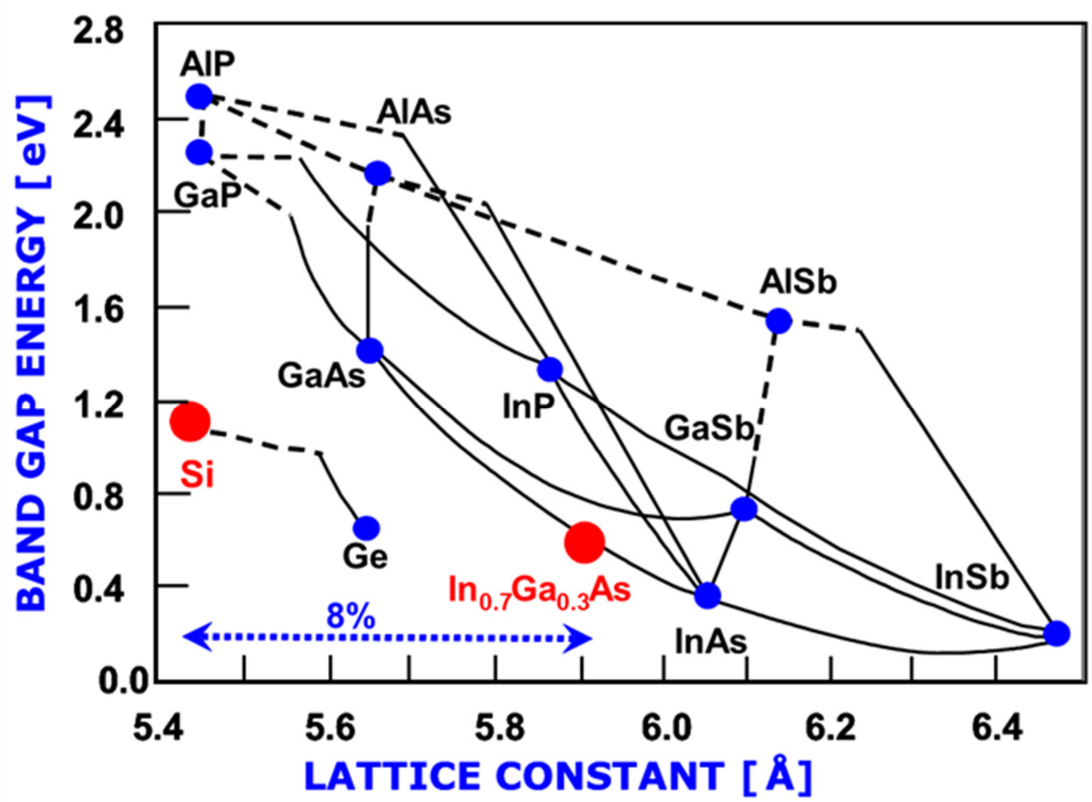
III-V RTD direct growth on silicon

From the band-gap vs. lattice constant plot it can be seen that there is an 8% mismatch in lattice constant between Si and InP or InGaAs. The inclusion of Ge reduces this mismatch to 4% and offers advantages over Si for compound semiconductor growth due to close lattice-matching with GaAs and easier growth nucleation. The quality of the Ge growth on the silicon substrate plays a crucial role in determining the quality of the final III-V layers used for the device construction.



Above: Schematic of one potential iBROW wafer structure

Left: A graph showing band gap vs. lattice constant for a range of key semiconductor materials.

As a consequence of lattice mismatch and relaxation of epitaxial layers, an increase in surface roughness and a degree of cross-hatching becomes apparent for RTD layers grown on non-native substrates. Improvements in this are expected when the RTD layers are grown on the latest low threading dislocation density (TDD) Ge-on-Si substrates.

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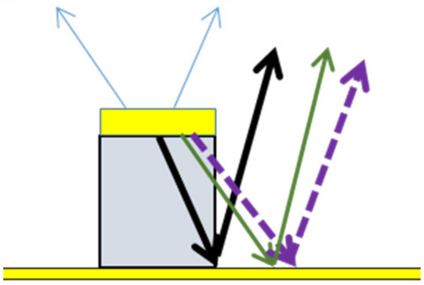
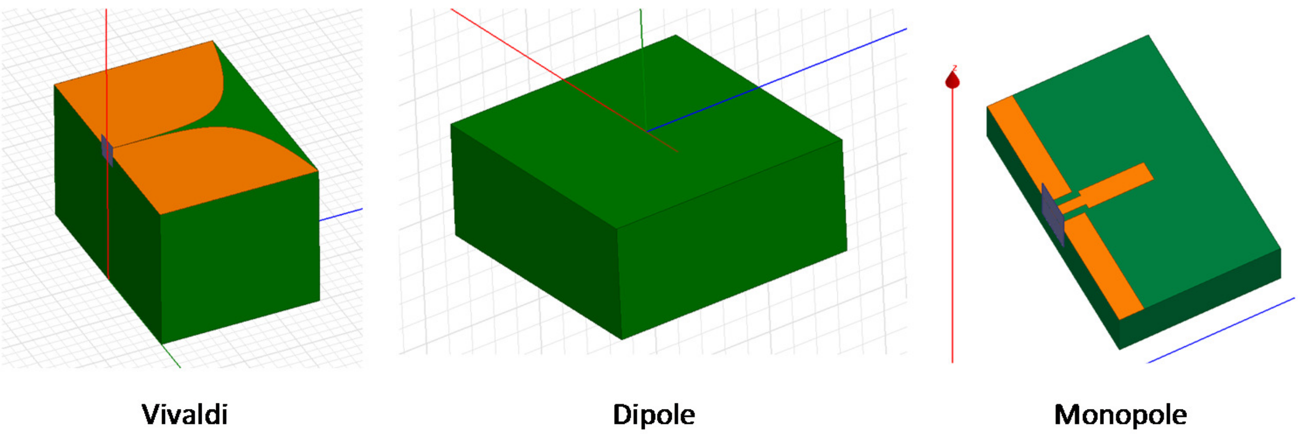
Integrated antenna design

RTDs with integrated antennas are under investigation in iBROW. An integrated antenna allows for a much more compact device with higher performance as well as lower cost compared with the employment of external antennas. However, there is a fundamental problem with integrating antennas in high frequency ICs based on III-V semiconductor substrate materials, such as RTDs on InP. The high dielectric constant of the substrate means that the antenna radiates almost fifty times more power into the substrate than into the air. The part of the power that is radiated into the substrate at angles greater than the critical angle will become trapped in the substrate. A common solution has been to use hemispherical lenses to extract the signal from the backside of the substrate. However, this solution brings undesired additional complexity in the manufacturing and assembly of RTDs.

In iBROW several solutions are under investigation for addressing this challenge. A diced bow-tie antenna has already been demonstrated by University of Glasgow to be a suitable solution, with experimental results confirming simulation predictions. Since the large dielectric constant substrate around the antenna conductor is removed, radiation is no longer trapped in the substrate, and the antenna radiates to the air-side direction with the help of the ground plane underneath the diced substrate which acts as a reflector (see right hand figure).

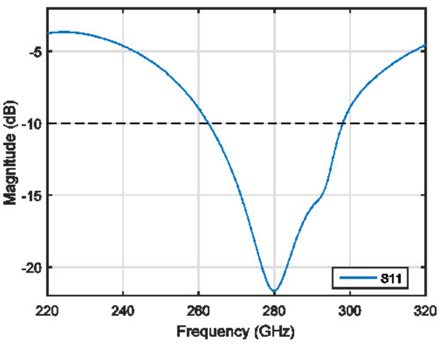


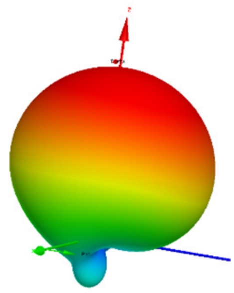
Schematic showing operation of a diced bow tie antenna

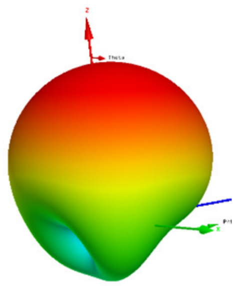


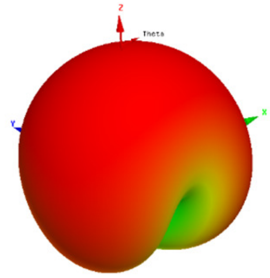
Schematics of the different antenna designs considered in iBROW

As part of this investigation, INESC has been evaluating different antenna designs for this application through simulation. The three designs considered are shown in the figure above: namely Vivaldi, monopole and dipole. Vivaldi is a traditional high-gain broadband antenna design. However, simulation results have shown that when operating over InP, the antenna radiation pattern becomes severely distorted due to the substrate effect. On the other hand, the dipole has provided a relatively stable radiation pattern, with the maximum gain varying between 5 and 8 dBi within the operational bandwidth of 25 GHz, from 270 to 295 GHz. Finally, the monopole was found to be the most balanced solution. As shown in the figure on the following page, while the gain achieved is moderate, varying between 3 and 5 dBi across the operational bandwidth (between 260 and 300 GHz), the radiation pattern remains fairly stable within the operational bandwidth and the 40 GHz of achieved bandwidth is larger than that achieved with the dipole.









Monopole frequency response | **4.5 dBi @ 260 GHz** | **5 dBi @ 280 GHz** | **3 dBi @ 300 GHz**

Monopole frequency response and radiation pattern within the operational bandwidth

Ongoing work is focused on further improving the monopole design by considering the entire InP slab in the antenna simulation, as well as considering different substrate thicknesses and monopole shapes.

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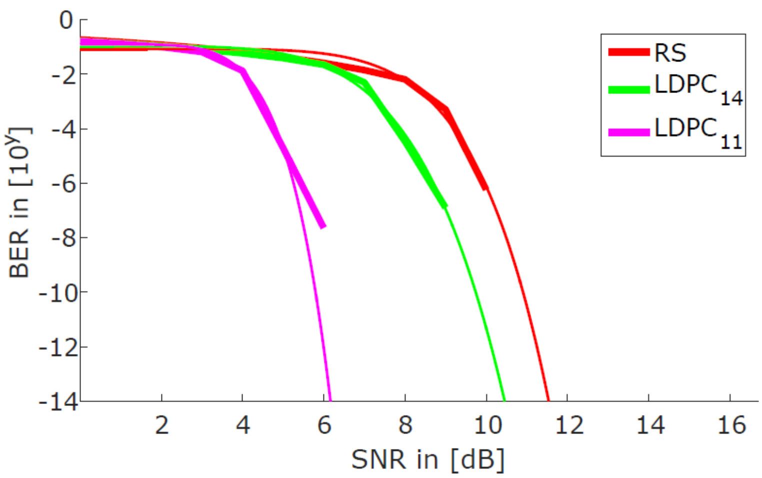
Standards work for 300 GHz wireless comms

In July 2016 members of the iBROW consortium submitted a preliminary proposal to the standards task group IEEE 802.15 TG 3d which is developing an amendment to the standard IEEE 802.15.3-2016 for switched point-to-point connections operating at 300 GHz. The preliminary proposal included a physical layer mode based on On-Off-Keying (OOK), which can be applied to the electronic RTD technology developed in iBROW. This mode was also included in the final proposal submitted in September 2016. The target applications for the OOK PHY mode are point-to-point links over distances of a few centimetres for kiosk downloading as well as intra-device communication. In order to explore the performance of the three proposed Forward Error Correction Schemes (FEC) a link level simulator was set up using the channel models defined in IEEE P802.15.3d.



BER curves for the Reed Solomon code (RS), the rate 14/15 LDPC code (LDPC 14) and the rate 11/14 LDPC code (LDPC11)

The figure shows the simulated BER curves of the proposed (240,224)-Reed-Solomon-Code, the rate-14/15 LDPC (1440,1344) code and a rate-11/15 and 11/14 LDPC (1440,1056) code for the kiosk downloading scenario for a channel model derived for 12 dBi antennas on both sides of the link. It can be observed that the two LDPC codes perform better than the Reed Solomon code. Still the Reed-Solomon code is attractive for the low cost implementations targeted in iBROW since, in contrast to the LDPC codes, it does not require soft decision information and allows less complex receiver implementations.

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